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METHOD FOR COMPENSATING TRANSPORT LAGS IN COMPUTER IMAGE GENERA--ETC(U)

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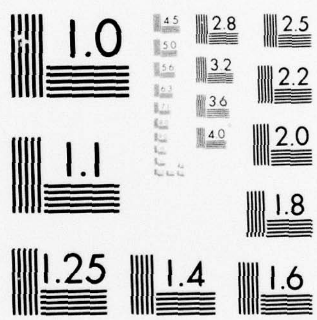

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HUMAN RESOURCES

METHOD FOR COMPENSATING TRANSPORT LAGS IN COMPUTER IMAGE GENERATION VISUAL DISPLAYS FOR FLIGHT SIMULATION

By

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NOTICE

This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with HQ Air Force Human Resources Laboratory, Brooks Air Force Base, Texas 78235.

This technical report has been reviewed and is approved for publication.

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This paper examines an analytical technique for simultaneously compensating transport delays in Computer Image Generation (CIG) visual systems, while eliminating high frequency "flutter" effects.

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PREFACE

This study was conducted in support of project 1123, Dr. Milton E. Wood, Project Scientist, and work unit 11230301, Mr. Michael L. Cyrus, Principal Investigator. This study was conducted by the Flying Training Division, Air Force Human Resources Laboratory, Williams AFB, Arizona.

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METHOD FOR COMPENSATING TRANSPORT LAGS IN COMPUTER IMAGE GENERATION VISUAL DISPLAYS FOR FLIGHT SIMULATION

I. INTRODUCTION

One of the major problem areas in flight simulation today is integration of visual, motion, and aerodynamic subsystems. A particular subproblem is the compensation of the visual subsystem to correspond to the aerodynamic (usually called "flight") system. This compensation is normally both software and hardware controlled. In Computer Image Generation (CIG) systems, a fixed transport lag on the order of 50 to 100 milliseconds needs to be compensated. After compensation is achieved, the resulting output is smoothed to remove flutter effects. This paper introduces a general method for this compensation.

II. PROBLEM FORMULATION

1. Basic Assumptions

a. The primary iteration interval of both the flight and visual systems is h (a typical value for h is 1/30 second). This is not a limitation to the method, but certain modifications must be made if interpolated output to the visual processor is used.

b. After each flight output, position, velocity, and acceleration data are current for all orientation and position variables.

c. The flight output is considered accurate; that is, we treat the simulation mathematical model as though it were representative of the actual aircraft.

d. The sequence of future accelerations and the position, velocity, and acceleration at any moment in time serves to define the entire position and velocity history forward.

2. Integration

From our assumptions, we have the following integration model for arbitrary variable v (here "." denotes the usual differentiation with respect to time).

Position	v_{n-2}	v_{n-1}	v_n	v^p_{n+1}	v^p_{n+2}	$v^p_{n+2+\tau}$
Velocity	$\dot{v}_{n-2}$	$\dot{v}_{n-1}$	$\dot{v}_n$	$\dot{v}^p_{n+1}$	$\dot{v}^p_{n+2}$	$\dot{v}^p_{n+2+\tau}$
Acceleration	$\ddot{v}_{n-2}$	$\ddot{v}_{n-1}$	$\ddot{v}_n$	a_1	a_2	α
Time	(n-2)h	(n-1)h	nh	(n+1)h	(n+2)h	(n+2+τ)h
	Known			Predicted		

Figure 1

Where $0<\tau\leq 1$ for illustration purposes.

Assumption (1d) implies that the knowledge of a_1, a_2, α together with v_n, $\dot{v}_n$, and $\ddot{v}_n$ determine $\dot{v}^p_{n+1}$, $\dot{v}^p_{n+2}$, $\dot{v}^p_{n+2+\tau}$, v^p_{n+1}, v^p_{n+2}, and $v^p_{n+2+\tau}$. Consider, for example, the trapezoidal method of integration, where:

$$\dot{v}_{n+1} = \dot{v}_n + \frac{h}{2}[\ddot{v}_{n+1} + \ddot{v}_n]$$

$$v_{n+1} = v_n + \frac{h}{2}[\dot{v}_{n+1} + \dot{v}_n]$$

This method is clearly of the type specified by paragraph 1d.

Figure 1 highlights another important property of CIG compensation, namely, that the final variable to be predicted (in this case $v^p_{n+2+\tau}$) may not lie evenly on an integral multiple of h. For our purposes, it is necessary to consider the integration operator as a continuous one. Normally, we may retain the acceleration derivative sequence values up to any desired length and the prediction point in the future may require extrapolation forward any number of iteration intervals. However, many prediction techniques also induce flutter, the rapid oscillatory response of a visual system to high frequency pilot control inputs; therefore, it is desirable to couple, in line, a low-pass filter to remove high frequency effects. This leads us to the formal definition of the compensation problem.

3. CIG Transport Compensation Definition

For each variable, v, required by the visual system for display purposes,

Given v_n, $\dot{v}_n$, $\ddot{v}_n$, $\ddot{v}_{n-1}$, ... $\ddot{v}_{n-\ell}$, find coefficients c_1, c_2, c_3, ..., $c_{\ell+3}$ such that

$$p^*_n = c_1 v_n + c_2 \dot{v}_n + \sum_{i=o}^{\ell} c_{3+i} \ddot{v}_{n-i}$$

is a "smooth" approximation to $v^p_{n+k+\tau}$

where k, and $o < \tau \leq 1$ are given.

Here the only open ended definition is that of "smooth." Some researchers have defined a more training oriented definition (Ricard, Norman, & Collyer, 1976). However, the generalizability of our technique is partially due to the capability of adjusting this smoothness parameter for each degree of freedom of aircraft motion.

Problem Solution

Since the integration technique itself is completely deterministic, we can find constants, I_1, I_2, I_3, I_4, ...I_{k+4} such that

$$v^p_{n+k+\tau} = I_1 v_n + I_2 \dot{v}_n + I_3 \ddot{v}_n + I_4 a_1 + I_5 a_2 + \ldots I_{k+3} a_k + I_{k+4}\,\alpha$$

where the parameters a_1, a_2, ..., a_k, α are determined as linear combinations of the $\ddot{v}_n$, $\ddot{v}_{n-1}$, ..., $\ddot{v}_{n-\ell}$, and the coefficients I_1, I_2, etc. depending, in general, on h.

First,

$$a_s = \ddot{v}_n + s\nabla\ddot{v}_n + \frac{s(s+1)\nabla^2\ddot{v}_n}{2!} + \ldots \frac{s(s+1)(s+2)(\ldots)(s+\ell-1)\nabla^\ell\ddot{v}_n}{\ell!}$$

where $s=1, 2, 3, \ldots k, k+\tau (a_{k+\tau} = \alpha)$; (Hildebrand, 1956)

however, even though the above relation can be expressed conveniently in matrix operator form, a modification so that the vector $(\ddot{v}_n, \nabla\ddot{v}_n, \ldots, \nabla^{\ell}\ddot{v}_n)$ is transferred into $(\ddot{v}_n, \ddot{v}_{n-1}, \ddot{v}_{n-2}, \ldots, \ddot{v}_{n-\ell})$ is required. Using the notation of Hildebrand (1956) wherein

$$\binom{-s}{0} = 1, \binom{-s}{1} = s, \binom{-s}{2} = \frac{s(s+1)}{2!} \text{ etc,}$$

we can write the vector $(a_1, a_2 \ldots, a_k, \alpha)$ as the product of two matrices and the vector $(\ddot{v}_n, \ddot{v}_{n-1}, \ddot{v}_{n-2}, \ldots \ddot{v}_{n-\ell})$.

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ \cdot \\ \cdot \\ \cdot \\ a_k \\ \alpha \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \ldots \\ 1 & 2 & 3 \ldots \\ 1 & 3 & 6 \ldots \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ 1 & k & \frac{k(k+1)}{2!} \\ 1 & k+\tau & \frac{(k+\tau)(k+1+\tau)}{2!} \ldots \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \ldots \\ 1 & -1 & 0 & 0 \ldots \\ 1 & -2 & 1 & 0 \ldots \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ 1 & -\binom{\ell}{1} & \binom{\ell}{2} & -\binom{\ell}{3} \ldots \end{bmatrix} \begin{bmatrix} \ddot{v}_n \\ \ddot{v}_{n-1} \\ \ddot{v}_{n-2} \\ \cdot \\ \cdot \\ \cdot \\ \ddot{v}_{n-\ell} \end{bmatrix}$$

$$\text{or } \quad \vec{a} = T \quad * \quad B \quad * \quad \vec{\ddot{V}}$$

$$\text{General Term:} \quad \binom{-t_i}{j-1} = T_{ij}, \quad B_{ij} = \begin{cases} (-1)^{j-1} \binom{i}{j-1} & i \geq j \\ 0 & i < o \end{cases}$$

where $t_i = i \qquad i=1, 2, \ldots, k$

$t_{k+1} = k+\tau$

Imbedding $\vec{\ddot{v}}$ into $\vec{v}_n$ by

$$\vec{V}_n = \begin{bmatrix} v_n \\ \dot{v}_n \\ \hdashline \vec{\ddot{v}} \end{bmatrix}$$

and $\vec{a}$ into $\vec{a}_n$ by

$$\vec{a}_n = \begin{bmatrix} v_n \\ \dot{v}_n \\ \ddot{v}_n \\ \hdashline \vec{a} \end{bmatrix}$$

$$\vec{I} = \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ \cdot \\ \cdot \\ I_{k+4} \end{bmatrix}$$

and

$$M_1 = \left[\begin{array}{c:c} \underset{3X3}{I} & \underset{3X\ell}{0} \\ \hdashline \underset{(k+1)X3}{0} & \underset{(k+1)\,X\ell}{0} \end{array}\right]$$

Here we imbed the $(k+1)\ X(\ell+1)$ product T^*B into the $(k+4)\ X\ (\ell+3)$ product M_2.

$$M_2 = \left[\begin{array}{cc} \underset{3X2}{0} & \underset{3X(\ell+1)}{0} \\ \hdashline \underset{(k+1)X2}{0} & \underset{(k+1)\,x\,(\ell+1)}{0} \end{array}\right]$$

Simplifying notation, we let

$$M = M_1 + M_2$$

implying that

$$\vec{a}_n = M\vec{V}_n$$

and

$$V^{p}_{n+k+\tau} = \vec{I}'\vec{a}_n$$

with these conventions,

$$V^{p}_{n+k+\tau} = \vec{I}'M\vec{V}_n$$

Finally, letting $\vec{C}' = \vec{I}'M$
we have

$$V^{p}_{n+k+\tau} = \vec{C}'\vec{V}_n$$

where $'$ denotes transpose. That is, the scalar estimate of $V^{p}_{n+k+\tau}$ is just the inner product of a fixed vector C and the vector $\vec{V}_n$, of held data. The selection of C (equivalent to a bounded linear functional over the Hilbert space for which $\vec{V}_n$ is a vector) is precisely determined by the topology induced on the space containing $\vec{V}_n$ by the integration method used. The remaining structure on the space is defined by the low-pass filtering requirement. Although several first order filters are available, we have chosen Butterworth filters. These filters possess the advantages of smooth magnitude and phase response. The interested reader should consult Oppenheim and Shafert (1975), and Sterns (1975) for additional information regarding digital filtering methods.

For notational convenience, we adopt the notation $\hat{P}_n = V^{p}_{n+k+\tau}$ as th demanded position prediction at time nh for the CIGs, and p^*_n as the optimum (filtered) position. The two are related by

$$p^*_{n+1} = fp^*_n + \frac{(1-f)}{2}(\hat{p}_{n+1} + \hat{p}_n)$$

where $0<f<1$ is the Butterworth filter constant.

Substituting $\hat{p}_n = \vec{C}'\vec{V}_n$, $\hat{p}_{n+1} = \vec{C}'\vec{V}_{n+1}$ gives

$$p^*_{n+1} = f\,p^*_n + \left(\frac{1-f}{2}\right)\vec{C}'(\vec{V}_n + \vec{V}_{n+1})$$

with initial condition given by $p^*_o = \hat{p}_o = \vec{C}'\vec{V}_o$

Due to the simplicity of the above form, it may easily be executed either by software or hardware.

Remarks and Recommendations

With appropriate modifications, this technique can be extended to combinations of transport and phase lag, as are common in model-probe visual systems. Due to its generalizability, off-line evaluations of candidate solutions to the overall integration problem, taking into account differing iteration rates, servo-characteristics, and simulation requirements is possible. Research conducted at the Naval Training and Equipment Center (NTEC) has demonstrated the positive value of such a technique (Ricard et al., 1976). We recommend the use of this analytical tool in the off-line analysis of full mission flight simulators for maximizing cue correlation.

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